

## TELEROBOTIC WORK SYSTEM: CONCEPT DEVELOPMENT AND EVOLUTION

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The basic concept of a telerobotic work system (TWS) consists of two dexterous manipulator arms controlled from a remote station. The term "telerobotic" describes a system that is a combination of teleoperator control and robotic operation. "Work" represents the function of producing physical changes. "System" describes the integration of components and subsystems to effectively accomplish the needed mission. Telerobotics reduces exposure to hazards for flight crewmembers and increases their productivity. The requirements for the TWS are derived from both the mission needs and the functional capabilities of existing hardware and software to meet those needs. Conditions imposed by the space environment make the space telerobot different from remote operating systems in the manufacturing industry, the nuclear industry, and the offshore petroleum industry. The TWS is only one manifestation of a space robot. There are analogous concepts derived from different control options, missions, and development paths. The systems-development approach recognizes dynamic, state-of-technology progress and the need for flight tests to support ground tests in producing an operational space system.

The initial mission for development of the TWS concept was the repair and servicing of satellites from the Space Shuttle Orbiter. Potential missions include the construction of large space systems and the maintenance of these systems. The Space Station has become a particularly attractive potential application for a TWS [1]. The station size requires a number of Space Shuttle flights for construction. Extravehicular activity (EVA) by the flight crew is currently the primary mode of assembly. Assistance by a telerobot could enhance operational margins and reduce astronaut exposure to hazards. The functional capability of the TWS should be equivalent to the capabilities of an EVA astronaut in order to assume tasks that are currently designed for performance by the crew in space suits [2]. Equivalence in manipulative capability also provides for contingency backup by the EVA crewman.

Applications of any telerobot design to the space operational environment must recognize that robotic or autonomous modes will be closely monitored. The operator will intervene when circumstances become hazardous or when the robotic mode is baffled by a particular task. Nevertheless, the use of robotics is imperative for the most effective utilization of the flight crew [3]. The qualitative relationship of teleoperation to robotic

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or automated performance of tasks in complexity and rate of accomplishment is illustrated in Figure 1. The objective of a smart adaptive space robot may be approached by designing for autonomous operations on simple tasks and increasing the capability to more complex tasks. An alternate approach is to use teleoperation with an inherent capability for performing complex tasks and incorporate supervisory and robotic techniques to increase the rate of performance. If a smart adaptive space robot is to be developed, evolution through teleoperation is the more conservative approach. Management regards teleoperation as a lower risk and as a potential backup to robotic performance. Teleoperation may be a slower path to a space robot because people tend to resist change and may continue to work in less productive modes. However, teleoperation evolution is a less restrictive approach than an autonomy evolution, which may require work site and task interface evolution as well.

The functions of telerobots in space are very different from the functions of terrestrial robots. Industrial robots are used in much more structured and repetitive operations. An industrial robot is highly productive when the task is well defined and the need for interaction with sensors is limited or easily characterized. The purpose of remote systems in the nuclear power industry is to preclude human exposure to an extremely hazardous environment. The adaptive potential of the human operator is used to accomplish complex and varied functions. In contrast to the conditions

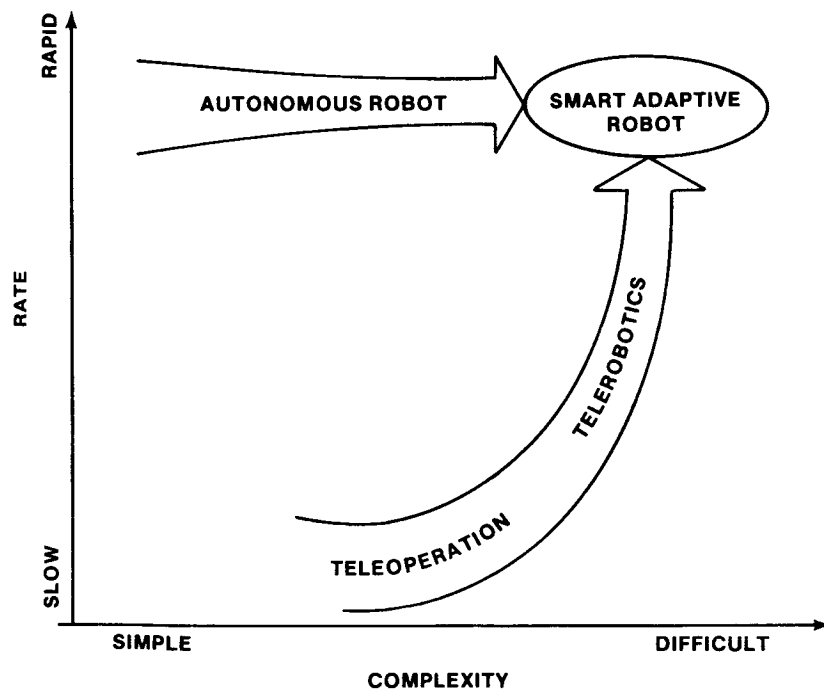


Figure 1. Robot capability development

in space robotics, operators are readily available and can be economically traded for system complexity. The remote operating vehicles in undersea applications also rely heavily on the operator's adaptive capability.

The idea for the use of TWS came from a study of the equipment needs for servicing satellites. Heretofore, EVA has been the primary resource for the performance of tasks in the repair and servicing of satellites. The highly successful Solar Max repair, the retrieval of Westar and Palopa, and the orbital refueling system demonstration confirmed the feasibility of using the Space Shuttle for in-flight maintenance of the orbiting vehicles. However, EVA by space-suited astronauts is risky and inefficient. The current flight rules require a buddy system as well as an intravehicular monitor. Also, just prior to extravehicular activity, crew members must breathe oxygen to prevent the adverse effects of the rapid decrease in air pressure. Though necessary for EVA, the breathing of oxygen and other preparations for cabin departure are nonproductive expenditures of crew time. The Space Shuttle's remote manipulator system (RMS) was designed for the deployment and retrieval of satellites, and it has no capability for dexterous tasks needed for servicing. In fact, the resolved rate control system for the RMS precludes tasks that constrain the motion of the arm. The addition of a force and moment sensor to the RMS is currently under development to provide limited RMS dexterity. The addition of small dexterous arms as an end effector for the large Shuttle arm (Figure 2) is the conceptual solution proposed by Grumman Aerospace Corporation (GAC) for enhancement of the RMS dexterity.

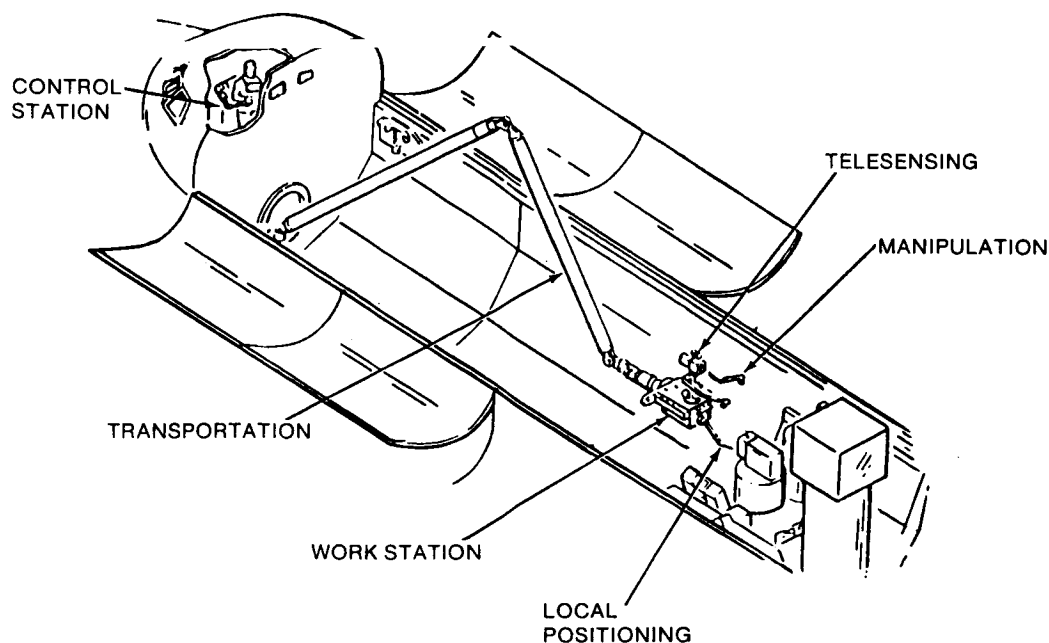


Figure 2. Definition of TWS systems

This initial concept was dubbed the "Telepresence Work System" and proposed to the Office of Aeronautics and Space Technology (OAST) as a technology development focus. During the same time, Martin Marietta Corporation (MMC) developed an analogous concept in their study of the remote orbital servicing system (ROSS) for use on the orbital maneuvering vehicle (OMV). Funding from the Office of Space Transportation Systems (OSTS) for satellite servicing equipment was applied to studies of the telepresence work system by Grumman and Martin. Subsequently, the studies were titled "Telerobotic Work System Definition Study." The basis for the name change was a recognition for the need for an evolutionary approach that would increase operator productivity. A telepresence system implies the objective of making the operator feel translated to the work site. The sensors and control modes would tend to enmesh the operator in the system. By emphasizing the telerobotic approach, the system design choices can enhance the evolution to robotic modes that expand productivity and place the operator in a supervisory capacity. The evolution from teleoperation to supervisory control to adaptive robotic control implies a capability to come back down the control scale to support robotic functions.

The contracted studies produced the telerobot concepts [4 and 5] illustrated in Figures 3 and 4. As might be expected from the EVA equivalency criteria, the resultant designs are strongly anthropomorphic.

The studies by GAC and MMC have concentrated on the satellite servicing functions and operation out of the Space Shuttle. The development plans

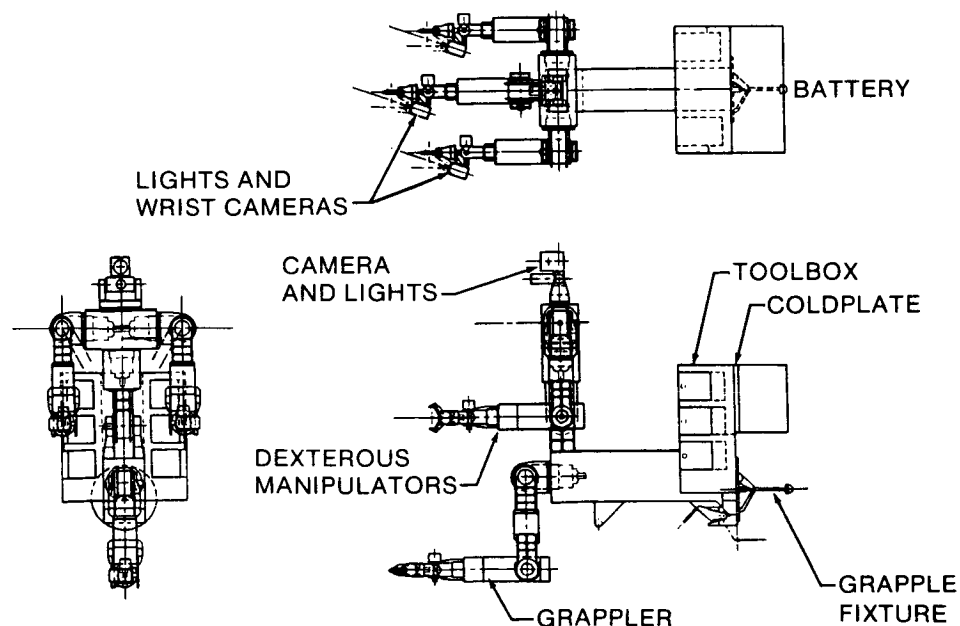


Figure 3. Grumman telerobot concept

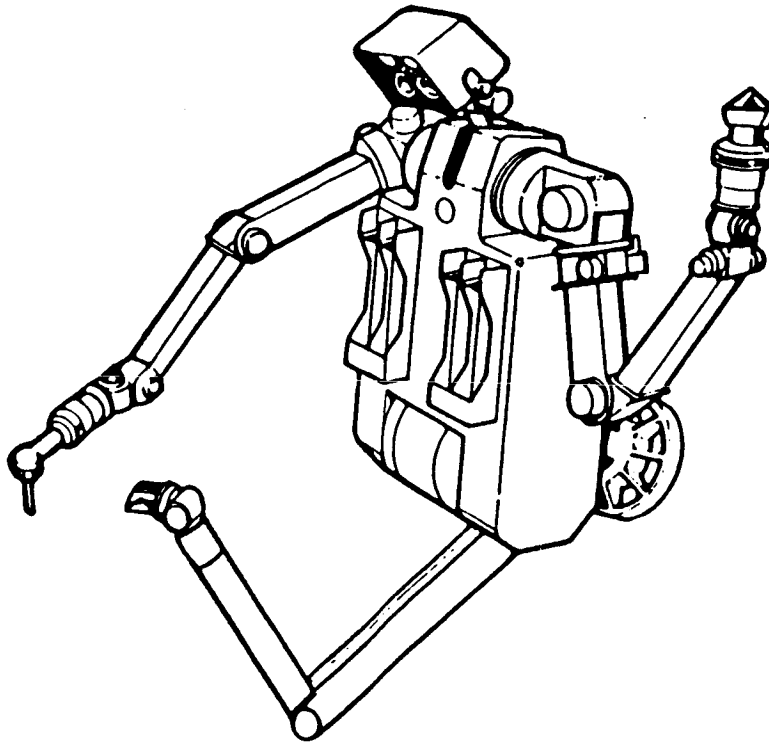


Figure 4. Martin telerobot concept

reflect the early need to demonstrate the feasibility and capability of a telerobot in these operations. However, development resources were expected to be severely limited in this mission application. Other missions were envisioned in the smart front end for the OMV and in the construction of the Space Station. Limited consideration was directed at these applications, although the functional capability to perform required tasks is little different from the satellite servicing tasks.

The development logic for the TWS is based on an evolutionary pattern. The potential development of technology can be expected to rapidly advance. Design features of subsystem modularity and robust computer capability should permit incorporation of technology enhancements with limited impact on the telerobot system. This approach is expected to be adopted for the flight telerobotic servicer program. The planning by the OAST is also consistent with the evolutionary approach for development of technology and the transfer of the technology to applications.

Much of the OAST program is concentrated in the telerobotic testbed at the NASA Jet Propulsion Laboratory (JPL)(Figure 5). Rather than a specific implementation of a set of ground test hardware, the testbed serves as a systems laboratory. The goal is to provide the necessary environment for resolving systems issues. There has been criticism that the equipment is

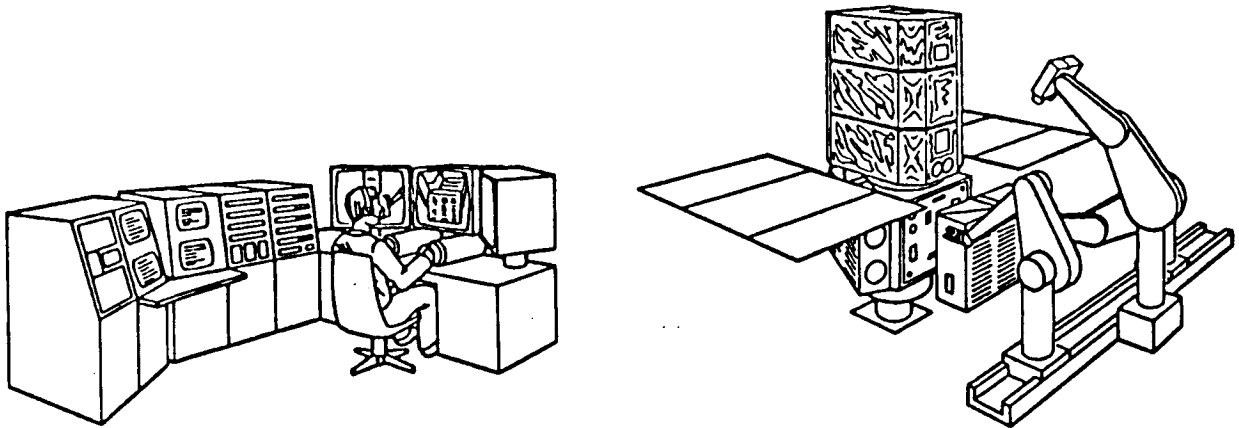


Figure 5. Telerobot demonstrator concept

largely state of the art. This view does not recognize the system-level considerations that must be examined in the light of the most advanced technology. Perhaps a valid criticism is the lack of zero-g simulations at JPL. Other facilities in NASA exist for effective simulation of the space environment, and these are being integrated into the overall program. Examples are the flat floors and neutral buoyancy facilities at Lyndon B. Johnson Space Center and Marshall Space Flight Center. Computer simulations are another way of evaluating operations. The validity of the ground simulations will eventually need correlation through test in the flight environment.

The categories for flight tests are: research, calibration of ground simulations, and development testing. Also, flight demonstrations may prove the technology ready for space applications and demonstrate task performance for specific missions. One aspect of research concerns human interaction with the displays and controls. The operation of controllers in zero-g depends on the type of control, the actuation forces, and the precision of positioning and movement relative to the axis system. To establish design parameters, researchers must evaluate the complex interaction of the controller with the physical characteristics of the manipulator arms. Force reflection is generally acknowledged to require less training in the performance of manipulation tasks on Earth. This has yet to be established for space operations. It will undoubtedly be dependent on the restraints of the operator. The operator's perception of the displays of various sensors may be biased by the environmental conditions.

It is generally recognized that the mechanisms used in manipulators and end effectors will react differently without the force of gravity either to bias the backlash in joints or to reduce the response to input forces. The mechanisms of the manipulator have critical interfaces in both directions, on the task side and on the operator/control side. At the task end, the objects being handled are not positioned and oriented by gravity. Assembly

tasks involving loose parts will require significant attention to control and positioning. There must be tethers or other positive attachments to preclude parts drifting off into space.

On the operator side of the system, the zero-g effects present a number of interactions relating mostly to the teleoperator mode of control. In the weightless environment, even the slightest force demands a response. For a force-reflection-type controller significant restraints will probably have to be provided. Restraints for a rate-type-controller may be as simple as guards or arm rests near the controller. The interactions between restraints and control inputs is a critical issue which needs additional testing.

Mechanisms perform differently in a zero-g environment. Backlash in joints and actuators may produce uncertainties that affect task performance. To take full advantage of the low loads on manipulator arms, the space design will be lighter and more flexible than analogous earthbound arms. The mechanisms and actuators also will be exposed to severe temperature extremes. Rejection of the heat generated by the actuators is not a trivial problem. Active thermal control systems are undesirable, leaving radiation of a duty cycle variable load by radiation as the prime mode. Heaters to maintain the lower limits of the performance envelope reduce available power and reliability. Interaction with the task will be particularly difficult to simulate on the ground.

A significant challenge in the development of a space telerobot will be to predict its effectiveness in an environment that combines a vacuum and a lack of gravity. The principal resource for such experiments is the Space Shuttle. However, because of the reduced number of Space Shuttle flights, it is difficult to obtain a listing on the payload manifest for this type of experimentation. Interfaces in the Orbiter cabin and the payload bay will limit the type and number of tests that can be used to validate ground simulations and to resolve several issues that are not amenable to simulation.

The development of a space telerobot represents a valuable resource in the performance of tasks in the unstructured and hazardous environment of space. As telerobotics proves itself in limited space applications, research will be initiated to expand its use, and technologies will develop rapidly to accommodate changing requirements. As a result of space pioneering, applications of telerobotics will extend to personal service functions for disabled and aged people and to hazardous situations such as are found in construction and agriculture.

## REFERENCES

- [1] Jenkins, L.; and Olsen, R.: Remote Operating Systems for Space-Based Servicing. ASME Conference on Computers in Engineering (Las Vegas, Nev.), Aug. 1984.
- [2] Jenkins, L.: Telerobotic Work Systems Concepts. AIAA/NASA Symposium on Automation, Robotics and Advanced Computing for the National Space Program (Washington, D.C.), Sept. 1985.
- [3] Holcomb, L.; Larson, R.; and Montemerlo.: Overview of the NASA Automation and Robotics Research Program. AIAA/NASA Symposium on Automation, Robotics and Advanced Computing for the National Space Program (Washington, D.C.), Sept. 1985.
- [4] Telepresence Work System Definition Study. Grumman Aerospace Corporation, Contract NAS 9-17229, 1985.
- [5] Telepresence Work System Definition Study. Martin Marietta Corporation, Contract NAS 9-17230, 1985.